

NASA Technical Memorandum 83643

Advanced Designs for IPV Nickel-Hydrogen Cells

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Prepared for the
Nineteenth Intersociety Energy Conversion Engineering Conference
cosponsored by the ANS, ASME, SAE, IEEE, AIAA, ACS, and AIChE
San Francisco, California, August 19-24, 1984



ADVANCED DESIGNS FOR IPV NICKEL-HYDROGEN CELLS

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ABSTRACT

Advanced designs for individual pressure vessel nickel-hydrogen cells have been conceived which should improve the cycle life at deep depths-of-discharge. Features of the designs which are new and not incorporated in either of the contemporary cells (Air Force/Hughes, Comsat) are: (1) use of alternate methods of oxygen recombination, (2) use of serrated edge separators to facilitate movement of gas within the cell while still maintaining required physical contact with the wall wick, and (3) use of an expandable stack to accommodate some of the nickel electrode expansion. The designs also consider electrolyte volume requirements over the life of the cells, and are fully compatible with the Air Force/Hughes design.

INTRODUCTION

As part of an overall effort to advance the technology of nickel-hydrogen batteries for possible use in an energy storage system, in low earth orbit (LEO), improved advanced designs for individual pressure vessel (IPV) cells have been conceived. The purpose of this effort is to improve the cycle life at deep depths-of-discharge (DOD). The approach has been to effect cell improvements through a continuing combined in-house and contract effort. Contemporary IPV nickel-hydrogen cell designs and results of cycle life tests conducted in-house and by others were reviewed to identify areas where improvement could result in a longer cycle life. A component improvement effort directed towards the physical properties of each of the individual components was initiated and improvements will be factored into the cell as evolved. Design philosophies have been developed related to oxygen and electrolyte management requirements. Existing technology was utilized where possible to minimize development cost and time.

The contemporary design cells (Air Force/Hughes, Comsat) are adequate for the Geosynchronous orbit (GEO) applications, where not many cycles are required over the life of the storage system. However for the demanding LEO applications, the current cycle life at deep depths-of-discharge (2000 to 8000 cycles) is not acceptable (1,2). Some

investigators report that this limited cycle life is mainly due to degradation of the nickel electrode. However, there are also indications that modifications to the contemporary designs should result in an improved cycle life (3). Some possible causes of degradation are: density changes of the active material during cycling which could cause fatigue of the nickel plaque (4) and structural damage to itself resulting in capacity loss; active material could flake or extrude from the electrode causing a loss of capacity and possible shorting of the cell (1,5). Extrusion of active material may also cause channeling of oxygen generated during charge. This could lead to "popping" caused by large concentrations of oxygen reacting with hydrogen at the hydrogen electrode (5) which could damage the electrode (4). Blistering of the nickel electrode during cycling could cause capacity loss (6). Change in pore distribution and electrode surface area can also result from active material expansion and contraction, which could effect electrolyte distribution and performance. It has been reported that the nickel electrode expands significantly during cycling (3). This could cause compression of the separators, drying of the stack, rupture of the polysulfone core and cell failure. This failure mode can be eliminated by modifying the cell design to accommodate expansion.

In this report advanced designs for IPV nickel-hydrogen cells are described which should have an improved cycle life at deep depths-of-discharge.

CONTEMPORARY DESIGNS FOR IPV NICKEL-HYDROGEN CELLS

The two main designs of IPV nickel-hydrogen cells in current use, are the Air Force/Hughes and Comsat cells. The Air Force cell is designed for LEO applications but is considered to be an all-orbit cell. The Comsat cell is designed for GEO applications.

The Air Force cell is illustrated in Fig. 1. It consists of a stack of nickel electrodes, separators, hydrogen electrodes, and gas screens assembled in a non back-to-back electrode configuration. The stack is packaged in a cylindrical pressure vessel,

with hemispherical end caps. This is made of Inconel 718 and lined with zirconium oxide which serves as a wall wick. The components are shaped in a "pineapple" slice pattern. The electrodes are connected electrically in parallel. In this configuration electrodes of different types directly face each other. Hence, since a high bubble pressure separator is used, the oxygen generated at the nickel electrode on charge is directed to the hydrogen electrode of the next unit cell, where it recombines chemically to form water. The fuel cell grade asbestos separators are extended beyond the electrodes to contact the wall wick. Hence electrolyte which leaves the stack during cycling will be wicked back into the stack. The nickel electrode consists of a sintered nickel powder plaque containing a nickel screen substrate which is electrochemically impregnated with nickel hydroxide active material by the Pickett process. The gas screens are polypropylene. The electrolyte is a 31 percent aqueous solution of potassium hydroxide. The stack configuration is referred to as a recirculating design.

The Comsat design is illustrated in Fig. 2. It also consists of a stack of nickel electrodes, separators, hydrogen electrodes, and gas screens. The electrodes are also connected electrically in parallel and are assembled in a back-to-back configuration. In this back-to-back configuration the same type of electrode faces each other. Hence, the oxygen generated on charge leaves the stack between the nickel electrodes and reenters between the hydrogen electrodes to combine chemically with hydrogen at the catalyzed hydrogen electrode. This cell does not use a wall wick for electrolyte management. The nickel electrode plaques were fabricated by the slurry process and were electrochemically impregnated with active material by a modified Bell process. The separators are fuel cell grade asbestos and the gas screens are vexar.

NASA ADVANCED CELLS

Overall Designs

Two different, but similar advanced design IPV nickel-hydrogen cells have been conceived. They are illustrated in Figs. 3 and 4. One is referred to as the catalyzed wall wick and the other as the recombination capsule design. They differ only in the method of oxygen recombination. Initially the nickel electrodes, hydrogen electrodes, gas screens, pressure vessel, and potassium hydroxide electrolyte concentration will be identical to the ones used in the state-of-the-Art Air Force/Hughes cells. However,

a component improvement effort directed towards the physical properties of each of the individual components has been initiated and improvements will be factored into the cells as they evolve. For both designs the electrode configuration is back-to-back as is the case for the Comsat cell. Both designs also use a wall wick, however portions of the wall wick are catalyzed for the catalyzed wall wick design.

Features of the advanced designs which are new and not incorporated in either of the contemporary cells are: (1) use of alternate methods of oxygen recombination; (2) use of serrated edge separators; (3) and use of an expandable stack. The designs also consider electrolyte volume requirements over the life of the cells, and are fully compatible with the Air Force/Hughes design.

Boiler plate cells of both designs will be built and cycle tested to verify design feasibility.

Oxygen Management

During the later part of charge and on overcharge oxygen is evolved at the nickel electrodes.

For both contemporary designs oxygen management consists of chemically recombining the oxygen generated during charge on the catalyzed hydrogen electrode surface to form water. This chemical reaction is very exothermic; hence care must be taken to limit the rate at which these two reactants come together. If a separator is used which has a pore size distribution that permits a certain degree of gas permeability, oxygen bubble buildup occurs and "popping" results as these accumulations of oxygen abruptly recombine. This can result in sintering of the catalyzed surface and/or local melting of the Teflon/catalyzed agglomeration that makes up the hydrogen electrode. If high bubble pressure separators are used in the back-to-back electrode configuration (Comsat design) the oxygen must travel along the face of the nickel, leave the stack and then reenter to recombine on the hydrogen electrode. In this case the recombination would be expected to take place around the outer perimeter of the electrodes. The concentration of chemical reactants could result in damage to the electrocatalyst surface of the electrode.

An improved method of oxygen recombination is to use a catalyzed wall wick. The oxygen evolved on charge between the back-to-back nickel electrodes, travels along the face of the electrodes to the catalyzed

wall wick where it recombines. The water formed is wicked into the stack because the asbestos separators are in contact with the wall wick. An oxygen seal is used at the inner edge of the nickel electrodes to preclude oxygen from bypassing the catalyzed wall wick by escaping into the stack core, and reentering to recombine at the hydrogen electrodes. The asbestos separator pore size distribution is such that it has a high bubble pressure thus denying the oxygen a direct path to the hydrogen electrode.

The catalyzed wall wick is fabricated by first depositing a thin zirconium oxide layer of wicking material on the inner surface of the pressure vessel, as is the case in the Air Force design. A platinum Teflon mixture is coated in stripes onto the zirconium oxide surface. The mixture is similar to that used to fabricate SOA hydrogen electrodes, and is cured in the same manner.

The advantages of using a catalyzed wall wick are (1) aids thermal management, as the heat of oxygen recombination is deposited at the pressure vessel wall rather than at the hydrogen electrodes in the stack, and (2) prevents damage to the hydrogen electrode due to concentrated bubbles of oxygen reacting (popping problem).

Another method of oxygen management would be to use oxygen recombination capsules between the back-to-back nickel electrodes. The high bubble pressure asbestos separator directs the oxygen into the capsule, which consists of recombination sites catalyzed with platinum. They are encapsulated with a vapor permeable coating to allow passage of the gases in and water vapor out, but remain hydrophobic to liquid. The coating must also isolate the catalyst electrically, otherwise it will react with the nickel electrode as a parasitic reaction. The water formed within the capsule is returned to the nickel electrodes in the vapor form. This method of oxygen management benefits the overall electrolyte management scheme, and helps prevent damage to the hydrogen electrode.

Expandable Stack

The SOA electrochemically impregnated nickel electrodes expand significantly due to cycling at deep depths-of-discharge compressing the separators. The electrolyte forced out is absorbed by the increased pore volume of the nickel electrodes. Hence expansion of the nickel electrodes effects electrolyte volume (as a percentage of stack saturation) and electrolyte distribution. This failure mode applies to the Comsat cell,

which does not use a recirculation stack. In the Air Force cell; the proper electrolyte volume should be maintained by the recirculation stack design. However, it has been reported by others that the Air Force cell has also failed due to nickel electrode expansion (7). In this case, the expansion was so great (about 1/2 in., 40 electrode stack) that the polysulfone core of the stack ruptured. This failure mode can be eliminated by modifying the cell design to accommodate expansion.

To accommodate the nickel electrode expansion and improve cycle life, an expandable stack has been proposed. One way of implementing this is to use inconel 718 Belleville disc springs at each end of the stack between the end plates and tie rod nuts. The springs will maintain stack compression throughout the life of the cell. Another way is to share the accommodation with the separator. The spring constant can be selected so that some of the electrode expansion is absorbed by the asbestos separator. A 10 mil separator, which is the standard thickness used in contemporary nickel-hydrogen cells, can be compressed to about 5 mils without any performance degradation provided it has adequate electrolyte. In SOA cells, the asbestos separators are initially compressed 1 mil to insure good component contact. As a matter of fact, the performance of the separator may improve due to the decrease in thickness. However, this could be offset by a change in tortuosity due to compression. The separator can be thought of as a spring in series with the Belleville spring. The relative deflection will depend on the respective spring constants.

An effort has been initiated in-house to investigate the effect of separator compression on resistance and electrolyte content.

Serrated Separator

The separators are made of beater treated asbestos (BTA) rather than conventional fuel cell grade asbestos. BTA is reconstituted fuel cell grade asbestos that has 5 percent by weight butyl laytex binder added (8). The sheet is formed in one ply and is approximately 7 mils thick. The properties of BTA are comparable to those of the fuel cell grade asbestos (resistivity, electrolyte retention, porosity, pore size, bubble pressure). In addition the BTA is more uniform and stronger. The edges of the separator are serrated to facilitate gas movement inside the cell. The (duty cycle) of

the serration is about 25 percent. Hence 75 percent of the separator edge will still be in contact with the pressure vessel wall for electrolyte management.

Electrolyte Management

Cell performance is very sensitive to stack electrolyte volume and distribution (9). There are many factors which effect this quantity, and some are difficult to control. However, by good design, proper electrolyte volume can be maintained over the life of the cell for good performance.

One way of maintaining the proper electrolyte volume is to provide extra electrolyte in the bottom of the cell (about 20 ml) and a means of transporting it to the stack as required. This can be done by extending the separators beyond the electrodes to contact the wall wick, which is in contact with the electrolyte reservoir, as is the case in the Air Force design.

CONCLUDING REMARKS

Advanced designs for IPV nickel-hydrogen cells have been conceived, which could have a longer cycle life at deep depths-of-discharge. The features of the designs which are new are; use of alternate methods of oxygen re-combinations, use of an expandable stack to accommodate nickel electrode expansion, and use of serrated edge separators to facilitate gas movement within the cell while still maintaining required physical contact with the wall wick. The designs also consider electrolyte volume requirements over the life of the cells, and are fully compatible with the Air Force/Hughes design.

Boiler plate cells of both designs will be fabricated and cycle tested to verify the design feasibility.

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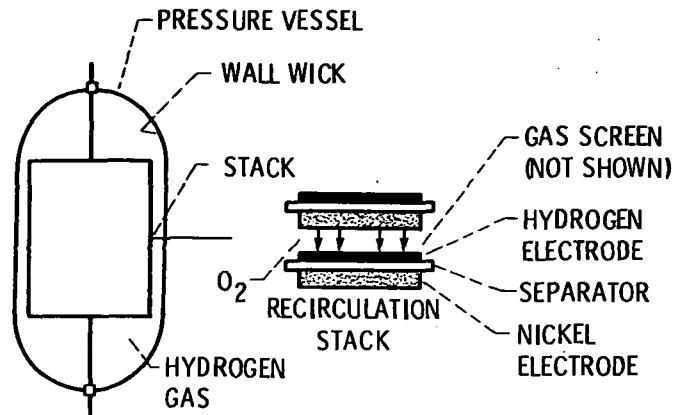


Figure 1. - Illustration of Air Force/Hughes design individual pressure vessel nickel-hydrogen cell.

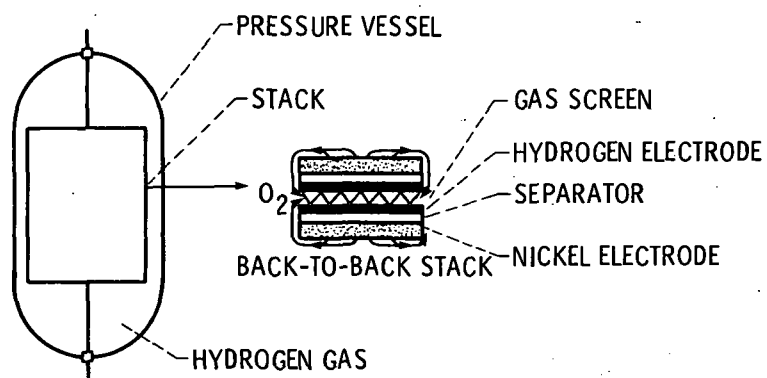


Figure 2. - Illustration of Comsat design individual pressure vessel nickel-hydrogen cell.

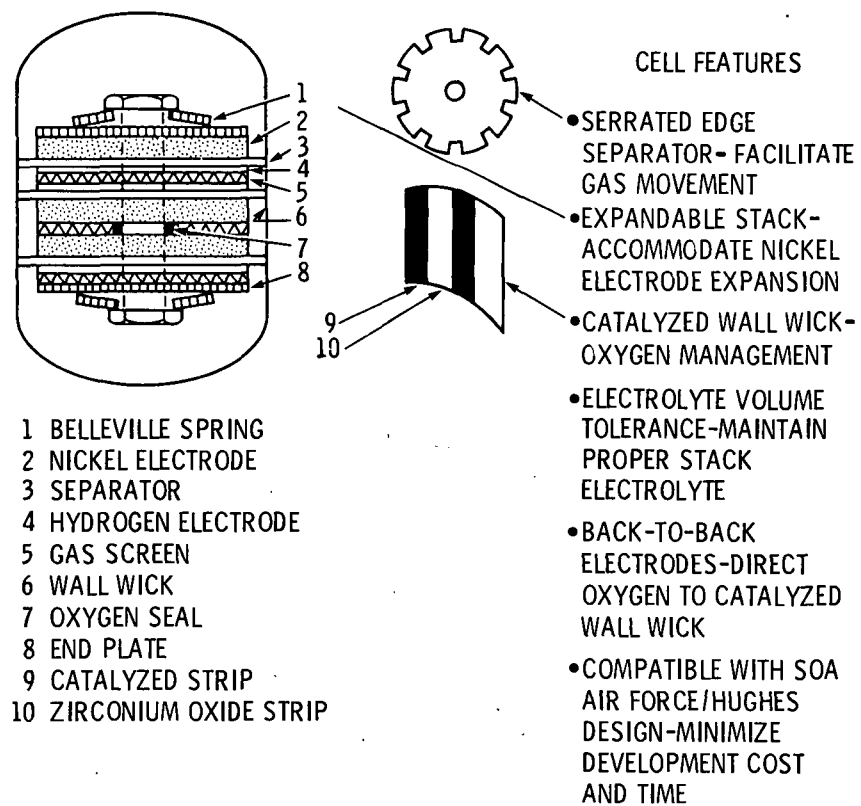


Figure 3. - NASA advanced design IPV nickel-hydrogen cell-catalyzed wall wick.

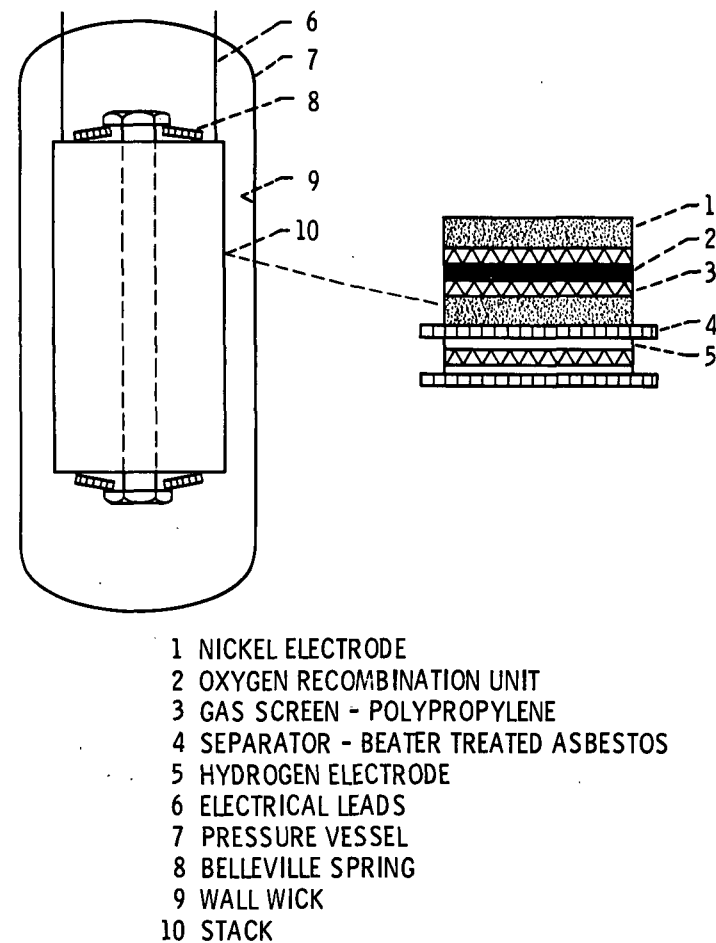


Figure 4. - NASA advanced design nickel-hydrogen cell - oxygen recombination capsule.

1. Report No. NASA TM-83643		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Advanced Designs for IPV Nickel-Hydrogen Cells				5. Report Date	
				6. Performing Organization Code 506-55-52	
7. Author(s) John J. Smithrick, Michelle A. Manzo, and Olga Gonzalez-Sanabria				8. Performing Organization Report No. E-2052	
				10. Work Unit No.	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared for the Nineteenth Intersociety Energy Conversion Engineering Conference cosponsored by the ANS, ASME, SAE, IEEE, AIAA, ACS, and AIChE, San Francisco, California, August 19-24, 1984.					
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17. Key Words (Suggested by Author(s)) Batteries Nickel-hydrogen batteries Energy conversion			18. Distribution Statement Unclassified - unlimited STAR Category 44		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of pages	
				22. Price*	

National Aeronautics and
Space Administration

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